Study on UAV Flight Based Identification Technology

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Abstract:

In order to verify the feasibility of applying identification technology to engineering control of such air vehicles as missiles, by taking into consideration the flight authenticity, repeatability, safety and reliability, the unmanned aerial vehicle (UAV) similar to missile flight control is selected as the controlled object. Based on identification theory and control guidance theory, this paper firstly makes theoretical analysis on UAV's identification technology, and then conducts flight practice to verify the theory. Firstly, The feasibility of UAV's closed-loop identification and the generation of excitation signals are studied. Secondly, identification experiments platform, namely UAV system platform, is constructed, including hardware platform and such software platforms as control guidance, signal transmission and data collection. Thirdly, multiple flight identification experiments are conducted on UAV, thus obtaining identification data. Finally, the mathematical model of UAV is obtained through analyzing and processing data, and this model is verified in time domain and frequency domain. Through a series of simplification method, a mathematical model, which is available in engineering, simplified and close to reality, is achieved, and its correctness is verified at last. The results show that identification's theory and ideology can be entirely applied to the engineering practice controlled by actual air vehicles.

1 Introduction

Many methods were used to acquire the objects model, such as analysis method, identification method. To missiles and other flight vehicles, a whole suit of method was established now. The most important method was wind tunnel experiments. Nevertheless, because of the huge cost and workload, the wind tunnel experiments is generally made on relatively important states, namely characteristic points, and other states are usually obtained through such mathematical methods as interpolation. Some errors were included in wind tunnel experiments, such as modeled errors, scaled errors, states errors and so on. Thus, to revise the tunnel experiments errors, flight identification method is needed.

In this paper, based on identification theory and control guidance theory, an unmanned aerial vehicle (UAV) platform was formed, some flight identification experiments was done. Then used the flight test data, we identified the UAV's transform function and simplified the orders of the transform function. At last, the flight data was used to validate the transform function. The result shows the identification result was identical well with the flight data. That means identification's theory can be entirely applied to other flight vehicles.

2 Identification theory

With an input signal to the system, then it can obtain an output signal. There is some relationship between input and output. Using this relationship the system model can be obtained. The best input signal is white noise signal, but it is difficult to act in flight experiments. A good substitute signal to white noise signal is pseudo-random signal, which can be generated through shift register easily. The Autocorrelation function of pseudo-random signal is illustrated as Eq. 1[1]:

$$R_{xx} = \begin{cases} a^2\left(1-\dfrac{N+1}{N}\cdot\dfrac{|\tau|}{\Delta t}\right) & (-\Delta t < \tau < \Delta t) \\ -\dfrac{a^2}{N} & (\Delta t \le \tau \le (N-1)\Delta t) \end{cases} \tag{1}$$

In Eq. 1, N represents cycle length, 0 represents sequence amplitude, and △t represents pulse period. It is obvious that when N is long enough, autocorrelation function can be approximately regarded as δ function. The selection of △t and N is a compromise proposal, it must be adjusted according to the practical process, the selection requirements of signal amplitude should not only ensure the linearity of the system, but also ensure the product's permissible tolerance possesses the largest amplitude.

When identified a continuous system, the discrete model was identified first, then with mathematical conversion the continuous model can be obtained. The input and output of discrete models can be illustrated using difference equation[2,3]:

$$\begin{aligned} & y(k)+a_1 y(k-1)+\cdots+a_n y(k-n) \\ & = b_1 u(k-d)+\cdots+b_m u(k-d-m+1)+\varepsilon(k) \end{aligned} \tag{2}$$

In Eq. 2, as the residual signal in the process of identification, $\varepsilon(k)$ exists as the system is disturbed by noises. According to different models of noises, the discrete models to be identified are divided into ARX, ARMAX, AR, MA and other models.

Through z conversion to Eq. 2, the ratio of output variable z conversion to input variable z conversion in zero initial condition is the system's z transfer function:

$$G\left(z^{-1}\right)=\frac{b_1+b_2 z^{-1}+\cdots+b_m z^{-m+1}}{1+a_1 z^{-1}+\cdots+a_n z^{-n}} z^{-d} \tag{3}$$

While using the ARX model, supposing one group of input signals, $u=\left[u(1),u(2),\cdots,u(M)\right]^T$, and one group of output signals, $y=\left[y(1),y(2),\cdots,y(M)\right]^T$, have been measured, the following equations can be obtained from Eq. 2:

$$\begin{aligned}
y(1)&=-a_1 y(0)-\cdots-a_n y(1-n)+b_1 u(1-d)+\cdots+b_m u\left(1-d-(m-1)\right)+\varepsilon(1)\\
y(2)&=-a_1 y(1)-\cdots-a_n y(2-n)+b_1 u(2-d)+\cdots+b_m u\left(2-d-(m-1)\right)+\varepsilon(2)\\
&\vdots\\
y(M)&=-a_1 y(M-1)-\cdots-a_n y(M-n)+b_1 u(M-d)+\cdots+b_m u\left(M-d-(m-1)\right)+\varepsilon(M)
\end{aligned}$$

In these equations, given the condition of $t\le 0$, $y(t)$ and $u(t)$ are supposed to be zero. The above equations can be written into matrix form as follows:

$$y=\Phi\theta+\varepsilon \tag{4}$$

In the above equation:

$$\Phi=\begin{bmatrix} y(0) & \cdots & y(1-n) & u(1-d) & \cdots & u(2-m-d)\\ y(1) & \cdots & y(2-n) & u(2-d) & \cdots & u(3-m-d)\\ \vdots & & \vdots & \vdots & & \vdots\\ y(M-1) & \cdots & y(M-n) & u(M-d) & \cdots & u(M+1-m-d)\end{bmatrix} \tag{5}$$

$$\theta^T=\left[-a_1,\ -a_2,\ \cdots,\ -a_n,\ b_1,\ \cdots\ b_{1m}\right]$$

$$\varepsilon^T=\left[\varepsilon(1),\ \cdots,\ \varepsilon(M)\right] \tag{6}$$

With least-square method, as long as the square sum of residual is minimum, $\min\limits_{\theta}\sum_{i=1}^{M}\varepsilon^2(i)$, the optimal estimated value of undermined parameter θ can be educed as:

$$\theta=\left[\Phi^T\Phi\right]^{-1}\Phi^T y \tag{7}$$

3 Setting the experiments

A small fixed wing UAV was chosen as the experimental method were used to identify the model of the UAV. The partial equipments of the experiments were shown in the Fig.1.

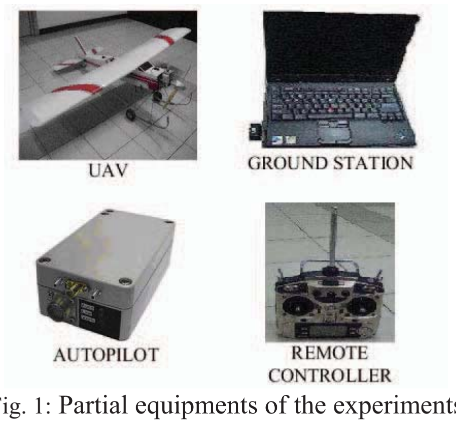

Fig. 1: Partial equipments of the experiments

The ground station was used to surveil the flight status of the UAV and transmit the instruction to the UAV through the radio frequency (RF) data link. The UAV can be guided both by autopilot and manual control system. The manual control was prior to the autopilot control. During the flight test, if the surveillance system found the UAV was in an abnormal flight way, the operator would switch the control to the manual control, and help the UAV restore safe flight by a manual wireless remote controller. The acquisition and storage system mounted on the UAV recorded the flight test data.

The MTI-G system (GPS aided MEMS based attitude and heading reference systems) mounted on the UAV provided the linear and angular position as well as linear and angular velocity. The airspeed meter provided the airspeed of the UAV. The atmospheric press altimeter provided the current absolute height of the UAV. When in autopilot control mode, the autopilot may calculate the command according to the position error between the target and the UAV, and then control the aerodynamic control surface to deflect a required angle to eliminate deviations.

Based on existing hardware systems, the software of UAV guidance and control system is designed. Firstly, the UAV's initial autopilots are designed according to empirical data, and because PID control possesses such advantages as simple structure, good robustness and high reliability, these autopilots are designed with PID control structure. These control parameters are based upon previous empirical data, so they are not always suitable to the UAV. Therefore, based on initial design, it is necessary to conduct PID self-adjusting on control parameters through actual flight test, thus obtaining relatively correct PID control parameters which are suitable to this control object, in order to achieve the precise control of the UAV.

Guidance and control system's basic block diagrams deigned by use of classic control theory are illustrated in Figure2, 3 and 4[4]. Figure 2 illustrate aileron and rudder control. This UAV's course is quiet, stability is high, and its rudder surface is small, therefore, if it turns with the form of STT, the turning radium will become longer, and the sideslip angle will be increased, thus causing serious coupling of rolling direction and yaw direction, which is disadvantageous to UAV flight control. Therefore, during the process of design, the form of BTT is adopted when the turning curvature is high, and at the same time rudder is used to decrease the sideslip of UAV[5].

Figure 3 illustrate the elevation control. Guidance loop adopts contour level flight strategy, inner loop uses elevating attitude angle pilot, and it also uses elevating rate signal as damping feedback signal, namely D signal in PID control. The UAV's height and rate are changed along with the changes of its throttle rudder and elevating rudder. During the process of design, the coupling between throttle rudder and elevating rudder are removed, with elevating rudder only used to control height and throttle rudder to control the airspeed of UAV. Furthermore, through actual flight test, such kind of decoupling measure will cause less error.

Figure 4 illustrate the airspeed control, with the aim to ensure the basic constancy of UAV flight airspeed through controlling the throttle rudder. Because wind speed interferes significantly with UAV during its flight, it is necessary to control airspeed, through which UAV can always keep basic constancy under downwind, adverse wind and upwind conditions.

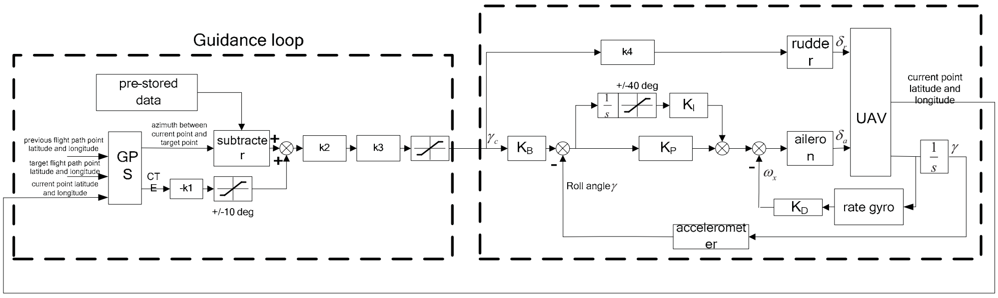

Fig. 2: rolling and yaw control

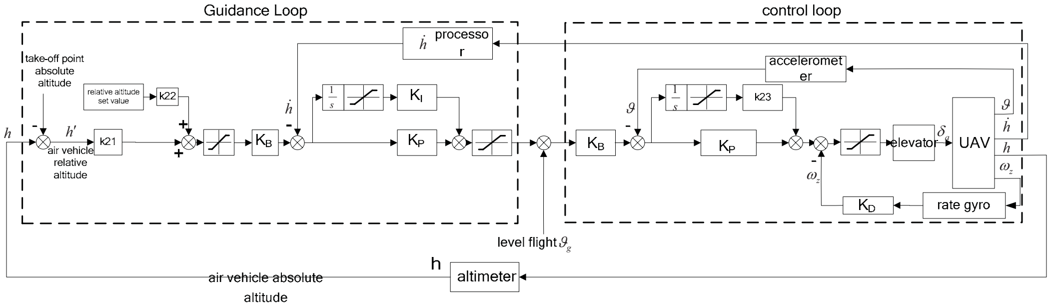

Fig. 3: elevating control

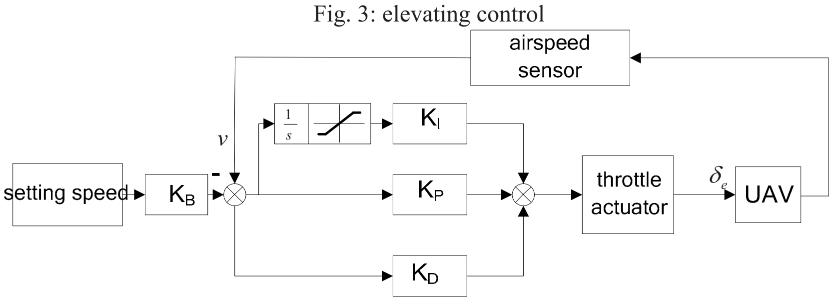

Fig. 4: airspeed control

4 Process of the experiments

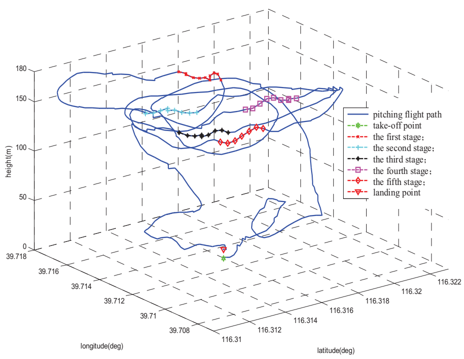

Fig. 5: pitching flight path

The auto regressive exogenous model and the least square method were used to identify the model of the UAV. The pseudo random binary signal was chosen as the input excitation signal. The excitation signal was added to the actuator's signal as the identification input. The angular velocity of the UAV was chosen as the identification output.

The experiments test was done for identifying the model transfer function which equals to the servo transfer function multiply the UAV airframe transfer function. All these identification process was similar. Figure 5 illustrates the flight path as well as selected identification experiment stages which add binary pseudo-random code. Figure 6 shows the flight test data.

In Figure 6 the top left figure describes excitation signal input, which uses pseudo-random sequence, and the cyclic symbols can be seen in the figure. The top right figure is identification signal input signal. Because of closed loop identification, this signal is shaped through the overlap of excitation signal and UAV closed loop feedback. From the figure, when there is no excitation signal, closed loop feedback is low frequency signal, whereas there is excitation signal, this overlap signal takes excitation signal as the main signal, that is to say the excitation of excitation signal is high frequency signal and it possesses leading position, so this closed loop identification can be achieved. The signals collected by output include pitching angle rate and pitching angle signals. The bottom left figure describes the pitching angle output signals, while the bottom right figure describes pitching angle rate signals. As the flight time of UAV is long, the accelerometer drift phenomenon is very serious, and furthermore, the error of angle measured by the combination of accelerometer and rate gyroscope is larger than that of pitching angle rate measured by rate gyroscope. Therefore, this identification takes pitching angle rate output as output signals. Seen from the bottom right figure, when there is excitation signals inputting, angle rate signals respond obviously.

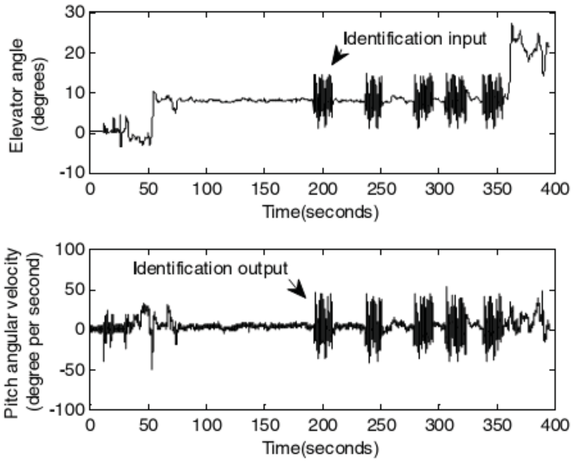

Fig.6: pitching direction input and output data

During the identification process, the number of steps of models must be estimated at first[6]. Through a series of theoretical experiments, it proves that when supposing the order of the model is 8, the model identified is better consistent with recorded data. That is to say, the higher the step of the model, the more the information contained in the model, and if the step of the model is too low, the identification results will be incorrect with inadequate information. Nevertheless, if the step of the model is estimated too high, the noises will become more and more, which meanwhile can cause incorrect model, so when determining the step of the model, the previous engineering experience and the comparison with recorded experimental data should be taken into consideration.

Firstly, high-order model is identified according to input and output. High-order conducts time domain verification with this model. The frequency response of these five continuous models was shown in Fig.7. Fig.7 shows the results keep consistency when the frequency was lower 10Hz. As UAV itself is an excellent low pass filter, the frequency band of the general air vehicles is lower than 6Hz, and this experiment takes signals before 10Hz to analyze.

Then the frequency response data which Flight tests data was lower than 10Hz was selected only. Based on the mean amplitude-frequency and phase-frequency characteristic of these five models, the least square method was used to fit a transfer function. The transfer function including the elevator and the elevator to the pitch angular velocity of the UAV was obtained.

$$\frac{5.74\left(\frac{s^2}{60.8^2} - 2*\frac{0.69}{60.8^2}s + 1\right)}{\left(\frac{s^2}{17.4^2} + 2*\frac{0.604}{17.4}s + 1\right)\left(\frac{s^2}{63.8^2} + 2*\frac{0.834}{63.8}s + 1\right)} \qquad (8)$$

To confirm the validity of this transfer function, the recording elevator data during the flight test was chosen as the input signal for the transfer function, and then calculating pitch angular velocity as the output of the transfer function was obtained. The comparison between the calculating result and the flight test data was shown in Fig.8. Fig.8 shows identification result correlate well with the experimental test results. Thus the identification model was accuracy and can be used with a reasonable degree of confidence.

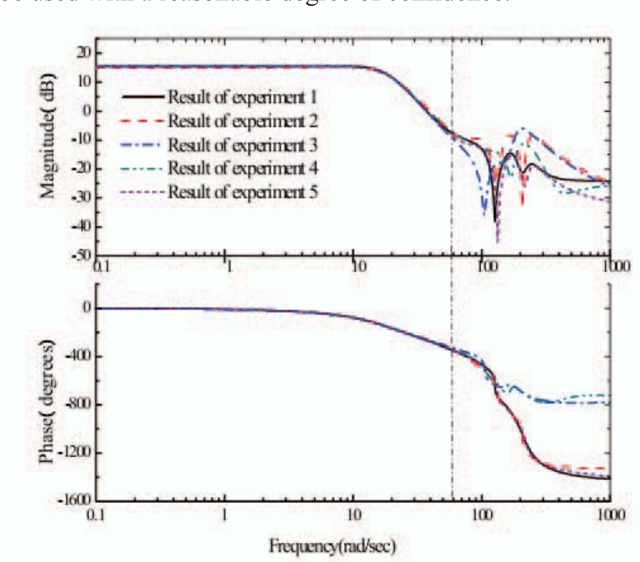

Figure 7 Bode-diagram comparisons of five groups of data

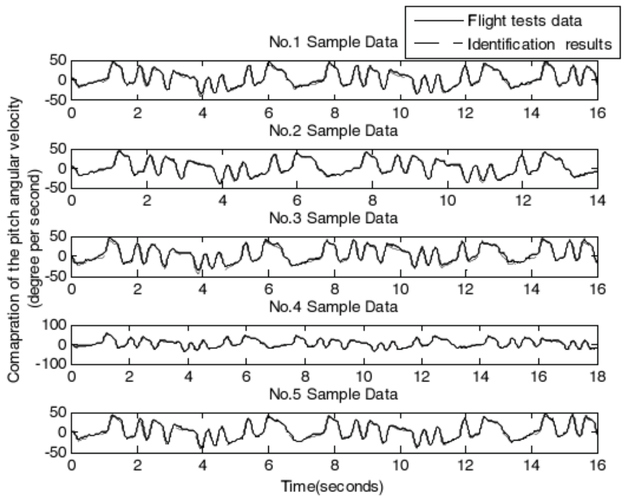

Fig. 8: Time domain curve comparisons between identified models and flight test data

Therefore, Eq. 8 is the final results obtained from pitching direction identification, and it is composed of pitching rudder transfer function and UAV body transfer function. Once observing the transfer function of Eq. 8, it is similar to the transfer function of a general UAV, so this identification method is reasonable, and the identification results reflects correctly the features of UAV.

5 Conclusion

Through analyzing system features, selecting reasonable excitation signals and obtaining the closed loop identifiability of UAV systems by analysis, this paper constructs UAV experimental platforms, and obtains experimental data from multiple experiments. This paper uses canonical difference equation to describe the system's dynamic features, and it also uses least-square methods to get the system's mathematical model. To verify whether the model is reasonable, this paper makes a comparison between identified results and recorded results in time domain, repeatedly verifies identified results in frequency domain, and even uses frequency domain mean data to reasonably simplify the results.

The results of analysis show that the above identification methods are reasonable and feasible, identification results are credible and correct, the simplification methods are feasible and the model of UAV and rudder can be obtained through identification. This model can be applied to a series of design and simulation processes, such as maturing the design of pilots, completing flight BTT adjustment turning simulation, and so on. The results show that identification technology can be applied to UAV engineering modeling and guidance control.

As the mathematical models of missiles are similar to UAV, identification technology can be spread to such air vehicles as missiles, and based on identification off line, it can be further applied to identification on line, thus improving control system and enhancing control precision. Identification technology will play an important role in air vehicle modeling and control.

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